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PROBLEMS OF BIOLOGY IN COSMIC FLIGHT

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by V. B. Malkin

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(Tsiolkovskiy's Concepts have been Transformed into Reality)

/This is a translation of an article written by V. B. Malkin, Candidate of Medical Sciences, in Priroda (Nature), No 10, Moscow, 1959, pages 35-44./

The launching of the first artificial earth satellites was realized in 1957, and on 2 January 1959 the first cosmic rocket was successfully launched in the direction of the moon. On 14 September 1959 at 0 hours 02 minutes 24 seconds a great historic event took place: the second Soviet cosmic rocket reached the surface of the moon. These events have opened a new era in the development of human culture -- the era of the conquest of space. Man has created flying apparatus capable of overcoming the force of terrestrial gravity, and, as a result, he will be able in the not too distant future to carry out flights in cosmic space. As a result of the outstanding achievements of Soviet science and rocket engineering, the age-old dream of man has come true -- a flight to the stars is possible. In this connection the attention of many millions of people is again attracted to the image of the eminent worker of Russian science, Konstantin Eduardovich Tsiolkovskiy, the man who at the dawn of the 20th century anticipated the great modern achievements. The name of this outstanding scientist, the founder of scientific aeronautics, is now universally known. However, Tsiolkovskiy not only worked on theoretical problems of reactive motion and on the construction of space ships, but a considerable part of his work was also devoted to medical and biological problems connected with human flight into space.

The problem of ensuring the life of men in cosmic space has interested Tsiolkovskiy during the entire length of his creative career. He has been reflecting for many years on the possibility of creating conditions for the maintenance of human life in cosmic space. In looking into the future, the great scientist and inventor wrote: "Humanity will not remain on earth forever, but in his quest for light and space will, at first, timidly penetrate beyond the limits of the atmosphere, and later will conquer all of space in the prox-

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imity of the sun." (1)

Even at the very beginning of his creative career, when Tsiolkovskiy only dreamed of interplanetary travel, it was already clear to him that, in addition to technical studies directed toward the creation of special flying apparatus, it would also be necessary to clarify the effect of such a flight on the organism of animals and man.

The scientific interests of K. E. Tsiolkovskiy were very broad. He was also interested in the most diverse facets of medical problems which originated in a flight beyond the earth -- those problems which are now so successfully being solved by Soviet researchers. Proof of these achievements is evident in the numerous successful launchings of one-stage ballistic rockets containing experimental animals. Some of these dogs -- as, for instance, Otvazhnaya /the brave one/ -- have flown into the higher atmospheric strata without deleterious effects on their health. Clear proof of the fact that these flights are entirely harmless to animals is evidenced by the healthy progeny of the dog Zhemchuzhnaya /Pearl/ after repeated flights (Fig 1). In order to fly into cosmic space, the space ship must, according to the descriptive expression of Tsiolkovskiy, overcome the "armor of earth's gravity" in developing an extremely high velocity (11.2 km/sec). It is therefore inevitable that the ship passengers will be subjected to the effect of mechanical energy. Will it have a harmful effect on the human organism; will it serve as an obstacle to man's breakthrough into cosmic space?

(1) K. E. Tsiolkovskiy, "Collected Works," Publishing House of Acad Sci USSR, Vol II, 1954, page 3

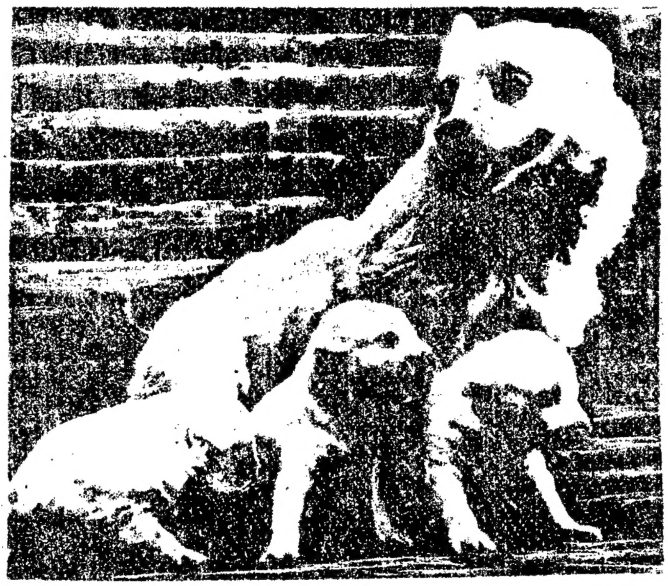

Fig. 1 The dog Zhemchuzhina and her progeny after her return from a flight into the upper strata of the atmosphere in a geophysical ballistic rocket on 10 July 1959.

It is possible that Tsiolkovskiy's interest in this problem originated in connection with his reading of the science-fiction novel of Jules Verne "From the Earth to the Moon," in which the protagonists of the novel, while getting ready to undertake a flight around the moon in a cannon shell and fearing that the inevitable immense pressure of the detonation of the "Columbiada" will crush them, decided to carry out a biological experiment. With this in view they placed a cat and a squirrel into the shell. After the successful completion of the experiment, the astronauts bravely commenced their flight into cosmic space. Before the flight, while waiting for the shot, they arranged themselves in the shell -- as the readers probably remember-- horizontally on the floor, below which was water to neutralize the effect of the colossal force of the thrust needed to impart cosmic velocity to the shell. A shot rang our, and the protagonists of the novel separated themselves successfully from the earth and rushed headlong to the moon.

Tsiolkovskiy understood that J. Verne's heroes (even if they could have created a cannon-shell capable of flying off into cosmic space) were bound to perish at the very start of their voyage, since the attainment of cosmic velocity during a very brief time interval would cause the

astronauts to be crushed by the mechanical energy acting on them during the gun powder explosion; without offering them any opportunity of protection. Thus, according to the computation of the French researcher Robert Eno-Pel'tri, when the length of the cannon barrel of the "Columbiada" would be equal to 300 m, the rate of acceleration would be such that the weight of the passengers would increase 280,000 times, a circumstance which would certainly cause their instantaneous death.

Tsiolkovskiy believed that the answer to the important problem in interplanetary flights regarding the effect of velocity accelerations on animal and human organisms can be obtained only by carrying out experiments. In this connection Tsiolkovskiy conducted experiments in 1876 and 1878, in which he studied the effect of centrifugal force on the organisms of animals and insects. In his autobiographical notes Tsiolkovskiy cites the following experimentation: "... I commenced experiments on chicks. I increased their weight fivefold on a centrifugal machine without causing them any harm, and I conducted similar experiments on insects even earlier in Vyatka." (1)

In speaking of Tsiolkovskiy's works, in which he elucidated the problem of the effect of acceleration and means of "rescue from excessive gravity," on the organism, it is necessary to note a remarkable quality of Tsiolkovskiy as a scientist -- namely that he was able to study the problems which interested him within a perspective plan and was also able to provide a clear program of the impending work. Thus, for example, he was firmly convinced of the necessity of carrying out experiments involving the rotation of a human being in a centrifugal machine. Such experiments, in his opinion, were bound to clarify the extent of accelerations, at any given time, which can be borne by man without substantial changes in the state of his health. At the same time one could test various means of protection during these experiments. The experiment must, as closely as possible, reproduce the flight conditions in the rocket. Thus Tsiolkovskiy indicated: "It is sufficient to conduct each experiment on increases of weight for two to ten minutes, i. e., as much time as it takes to produce an explosion in the rocket." (2)

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(1) K. E. Tsiolkovskiy. "My Life and Work." Publishing House of Aerofleet, 1939, page 28.
(2) K. E. Tsiolkovskiy. "Collected Works." Vol II, page 132.

The plan of study of this problem, which had been furnished by Tsiolkovskiy, has not been fulfilled. In the USSR and abroad aviation physicians are currently studying the effect of accelerations on the organisms of animals and man and widely employ centrifugal machines for this purpose. The modern centrifuges have a radius -- [equal to] the length of the arm -- from six to twelve meters, on which a cabin is installed. The necessity of a sufficiently large centrifugal radius is connected with the fact that in centrifuges with a small radius a man is subjected during rotation to the action of angular accelerations, which exert an unfavorable effect on his organism and impede the elucidation of effects caused by the action of radial accelerations.

In a modern centrifugal cabin man can assume any position, thereby permitting the study of the effect of accelerations which have various directions. The medical instruments placed in the cabin enable one to record the pulse, respiration, and the bioelectric potentials of the heart and cerebrum in the experimental subjects during the centrifugal rotation, while, by means of a television installation, one can observe the conduct of the individual and evaluate his general condition during the action of accelerations.

As demonstrated by the experiments of physiologists and aviation physicians, human resistance to the effect of accelerations depends on the direction in which the centrifugal force is exerted on his body, on the size of this force, and on the duration of its action. Accelerations which act in a direction corresponding to the longitudinal axis of the human body, i. e., from feet to head or from head to feet, have a particularly unfavorable effect on man.

In the majority of experiments human beings have been able to tolerate the effect of accelerations up to 3-5 G for a period of 10 to 30 seconds. In the case of higher accelerations serious disturbances of the activity of the central nervous system, originating as the result of the impairment of cerebral circulation, were observed in the experimental subjects. In cases where overloading acts in a head-to-feet direction, these disturbances are expressed as first a gray and, later, a black film in front of the eyes, after which loss of consciousness may take place. In case of overloading in a feet-to-head direction, a red film appeared in front of the subjects' eyes when 3 G were attained.

It has been established in experiments with a centrifuge that the most rational position of the subject's body is one in which the acceleration acts in a transverse direction, i. e., from the chest to the back, or from the back to the chest. Tsiolkovskiy thought that the astronauts must

assume a horizontal position during rocket ascent, i. e., must lie in such a way that the overloading will act in a transverse direction, in relation to the longitudinal axis of the body. Under such an effect of accelerations, the individual can tolerate accelerations ten to twelve times greater than the force of the earth's gravity for a relatively long period of time. These data were taken into consideration by the Soviet scientists who prepared the dog Layka, for cosmic flight which prior to the flight had been subjected to special training on the centrifuge under the prolonged effect of transverse accelerations. As is known, during its flight in the second artificial earth satellite, Layka successfully withstood the effect of accelerations during the period preceding the entry of the satellite into the given orbit. As demonstrated by the results of physiological studies, only an increase in the frequency of respiration and cardiac contractions was observed in the dog during this period -- a phenomenon generally observed in animals under the effect of accelerations.

However, Tsiolkovskiy was still of the opinion that during rocket ascent and, especially during the period of return to earth, when the rocket will be losing velocity rapidly as the result of its braking in the condensed atmospheric strata, such accelerations may exert an effect which would require the special protection of animals and man. In 1891 Tsiolkovskiy became seriously occupied with the problem of developing ways to protect living organisms from the effect of accelerations. During that time he expounded the idea "of protecting weak substances and organisms from blows and jolts and increased weight by their immersion in a liquid equal to them in density." (1) In substantiating this idea Tsiolkovskiy showed profound knowledge of biology and a keen power of observation. He wrote: "Nature has utilized this method for a long time by immersing animal embryos, their brains, and other weak organs in liquids, which thus protect them from various injuries. Man, however, has made little use so far of this idea." (2) To prove the correctness of this idea Tsiolkovskiy carried out a very simple but convincing experiment, which he described in 1891 in the "Works

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(1) K. E. Tsiolkovskiy. "New Conclusions I Arrived At," Publishing House of Aerofleet, 1939, page 45.
(2) K. E. Tsiolkovskiy, "New Conclusions I Arrived At," Publishing House of Aerofleet, 1939, page 45.

of the Moscow Society of Lovers of Natural Science." An egg is immersed in a cup or glass of water; in order to increase the density of the liquid, kitchen salt is dissolved in water until the egg commences to rise from the bottom to the water surface. After the egg is in balance (i. e., neither descends to the bottom nor rises to the surface), one can strike the container against the table with great force without breaking the egg, while without water the egg will break even at a slight jolt. The idea was further developed by Tsiolkovskiy in his novel "Beyond the Earth." In order to protect themselves from the effect of acceleration -- increased weight -- the protagonists of the novel placed themselves during the ascent of the rocket and its return to earth in special chambers filled with a liquid having a density approximating the density of the human body. Respiration was effected through tubes which opened into the atmospheric air of the rocket. "...Our friends, wrote Tsiolkovskiy of the astronauts who left the earth, "will remain safe and sound because they are placed in a horizontal position in a liquid of density equal to that of their bodies."(1)

In 1930, while Tsiolkovskiy was still living, his concept of protecting animals from excessive weight by means of immersion in a liquid was successfully tested in an experiment devised by a group of Soviet scientists, the prominent researcher in the field of astronautics Prof N. A. Rynin, in collaboration with the physicians A. N. Likhachev, A. A. Sergeyev, V. M. Karasik, and others. It was demonstrated by the experiments of these researchers that the immersion of experimental animals in water substantially raises their resistance to acceleration effects; for example, upon the action of stressed, brief accelerations frogs proved to be able to tolerate a thousandfold augmentation of their weight.

Studies were subsequently begun abroad in Germany, Great Britain, and the United States in which the possibility was investigated of utilizing immersion in a liquid as a means of protection against the prolonged effect of radial accelerations.

In the initial research on animals and human beings the experiment was conducted with incomplete immersion of the body in water. In spite of that, one observed in all

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(1) "Idem." "Beyond the Earth" Publishing House of the Acad Sci USSR, 1952, page 48.

experiments an increase of the resistance of animals and man to the effect of accelerations. Thus, it was demonstrated in the works of H. Jasper (USA) and others, of and A. Holt (USA), who had used various methods on different species of experimental animals, that their partial immersion in water (head-feet) led to an increase of their resistance to positive accelerations. In this connection, it was elicited that the greater the body area that is immersed in liquid, the greater is the resistance to the effect of the accelerations. As shown by the results of experiments by A. Holt, the resistance to the effect of accelerations increased in connection with the fact that considerably fewer circulatory disturbances resulted from the effect of accelerations in experimental dogs immersed in water than in animals which had not been protected by water.

In relatively recent times an Italian researcher, Margaria, recorded the results of experiments in which experimental animals were completely immersed in a liquid of sufficiently high density, in order to augment their resistance to the effect of stress accelerations. A considerable increase of the resistance of animals to the effect of stress accelerations was observed. Frogs tolerated accelerations of up to 3,000 G without serious injuries, while small mammals proved to be able to tolerate a 1,000-fold or greater increase of their weightfor a short period of time. It was observed in these experiments that the protective action depends on the depth of immersion of the animals in the liquid and on the extent to which their lungs are filled with air. It decreases noticeably if the layer of fluid surrounding the animal is less than five cm, and it is also less pronounced during inhalation -- upon increasing the amount of air in the lungs.

Thus, if immersion in a liquid whose density approximates the mean density of the animal organism acts to increase resistance to the acceleration effect, can not this resistance to acceleration become limitless? For, on the basis of Archimedes law, one apparently could attain complete body equilibrium in a liquid by accurately calculating its /the body's/ density, thereby protecting animals and man from accelerations of any magnitude. However, the anti-overloading effect of immersion in a liquid is limited by the fact, first noted by Tsiolkovskiy, that various tissues of the organism have unequal density. It suffices to recall that the body of vertebrate animals has osseous tissue which possesses a comparatively high density, while pulmonary tissue which is filled with air during the process of respiration is of very low density. The latter fact accounts for

the phenomenon that the resistance of animals to the effect of accelerations is lowered during inhalation when they are immersed in water. This problem was discussed in detail in a recently published article by D. R. Morris, D. Ye. Beyskher, and D. D. Zariyello, who had studied the resistance of non-vertebrate and small vertebrate animals to the effect of accelerations during immersion in a liquid. Interesting experimental data are cited in this work which attest to the fact that low-organized monocellular animals, whose various cellular elements possess almost uniform density, are able when immersed in a liquid of a given density to tolerate effects of accelerations of amazing magnitude -- up to 200,000 G.

In centrifuge experiments German and American physicians observed an increase of man's resistance to the effect of accelerations upon immersion of the human body in water; this effect was the more pronounced, the greater the amount of body area covered by water. In 1942, V. Frank (Great Britain) carried out successful experiments with a hydraulic suit in flight; the suit increased the resistance to aviators to acceleration by two G's.

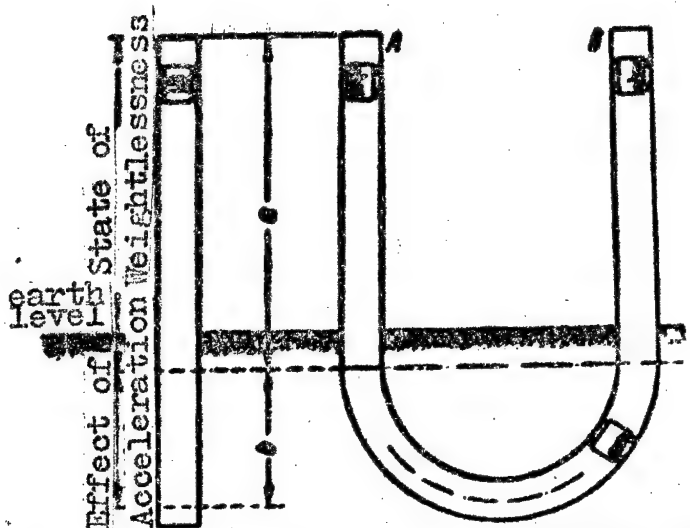
During the summer of 1958, in one of the laboratories of aviation medicine, experiments were conducted in which the experimental subject, wearing a light diver's suit, was completely immersed in a tank of water which had been fastened to a centrifuge. Results of these experiments on nine individuals showed that upon complete immersion in water a man, equipped with a light diver's suit, is able to tolerate the prolonged (over four minutes) effect of radical accelerations up to 13 G. Very recently, Gray, an American biophysicist, withstood the effect of acceleration of 31 G for over 15 seconds without substantial impairment of his health, under conditions of complete immersion in water within a powerful centrifuge. Thus, the correctness of Tsiolkovskiy's concept has been proved experimentally.

As is known, during a space flight when a rocket, having overcome the force of the earth's gravity, will fly in space with its engine switched off, all objects within, including the astronauts, will become weightless. The state of dynamic weightlessness also originates during a flight in an artificial earth satellite following its entry into the given orbit; it may also take place under certain flight conditions in rockets and planes. Lately, the effect of weightlessness on man has been given considerable attention in studies by foreign and Soviet authors. Works were published which characterize the flight conditions under which the state of weightlessness originates, as well as human

reactions under conditions of complete and partial weightlessness.

Tsiolkovskiy was the first to give a scientifically substantiated description of various methods of obtaining the state of weightlessness. He graphically described the methods of obtaining weightlessness and divided them into two categories: real and hypothetical. In reference to the hypothetical [category], the scientist described an ascent in a tower 37,000 km high (5.5 earth radii), as well as a journey in a train which moves along the equator at a speed of eight km/sec. In the latter case the "gravity was annihilated" in the train carriages by the centrifugal effect, but the air, of course -- as Tsiolkovskiy remarks -- would not let the train move at such a speed. Therefore, in order to obtain such a high rate of motion, a raised platform 300 km high, and reaching beyond the condensed atmospheric strata, would have to be constructed. Under these conditions one could obtain the initial cosmic speed. It is necessary to note that precisely these types of motions are effected at present by the artificial earth satellites.

As a more realistic method of obtaining a brief state of reduced weight and complete weightlessness, Tsiolkovskiy suggested the use of special cabins falling freely from great heights. Thus, for example, he indicated that if such a freely falling cabin were to be mounted on the Eiffel tower, which is 300 m high, and its braking were to be effected by water, the state of weightlessness under conditions of free fall would appear within eight seconds. This concept of Tsiolkovskiy is currently being put into practice by Soviet and foreign researchers. To study the effect of the brief action of reduced gravity and the subsequent increase of weight on human beings, high-speed elevators are employed; by means of their motion, partial weightlessness and an increase of weight are successively induced.



Acceleration in the straight tube

Acceleration in the U-shaped tube

Fig. 2 Schematic diagram of two possible gravitrons. Left -- a straight gravitron: the experimental subject enclosed in a hermetic cabin falls freely in the "a" segment in the vacuum of the vertical tube. In segment "b" he is braked to a complete stop and is then propelled upwards to repeat the cycle; right -- a U-shaped gravitron; it is similar to a straight gravitron, except that in the semicircular part of the device the direction of motion is changed and an overloading takes place. Thus, in this case, there is no need of slowing down, the velocity is maintained, and the braking is effected through friction in the curved section of the tube and can be compensated by means of additional acceleration.

To obtain a more prolonged state of weightlessness under surface conditions, Tsiolkovskiy suggested the utilization of a special device which he described as follows: "They are rails which have the shape of a magnet with the ends up, or of a horse-shoe; the cabin grips the rails from both sides and cannot come loose. In sliding down one leg of the horse-shoe, it makes a semicircle and travels up the other leg where it is retarded automatically in losing its velocity.

In the movement toward the semicircle the relative weight disappears; it reappears on the curve to a greater or lesser degree, depending on the radius of the semicircle, as an approximately constant phenomenon. Upon its ascent up the straight and steep rail it disappears again; it also disappears in the return fall if the cabin is not halted at the top. Thus the observational period of apparent absence of weight is prolonged."

Many years after the publication of Tsiolkovskiy's book, "Dreams of Heaven and Earth," in which the device of obtaining weightlessness was described, the American researcher Walton suggested in the journal, "Aviation Medicine," (1957) the use of a "gravitron" in studies of surface conditions in order to obtain weightlessness -- with this device one can induce such a state of weightlessness. The principle of performance of the "gravitron" consists in the fact that weightlessness appears upon the free falling of a cabin in a horse-shoe shaped tube 240 m high, from which the air is pumped out in order to eliminate friction (Fig 2). In reality, therefore, Walton only modified the work of Tsiolkovskiy which he had published in the last century.

In order to imitate the state of weightlessness in the training of astronauts Tsiolkovskiy suggested the utilization of immersion in water. However, he visualized clearly that immersion in water or even in a fluid with somewhat higher specific gravity will create a situation only slightly similar to the state of weightlessness. For, upon immersion in fluid, man remains within the sphere of action of earth's gravity, though his body is subjected to the uniform effect of a force which tends to push it out of water, as a result of which it seems to "lose its weight." However, the otolithic apparatus situated in the inner ear, which represents one of the receptors which signalize to the central nervous system on the weight of the body, will continue to function upon immersion in water and the internal organs will also retain their weight. In the case of man's movements the water will exert corresponding resistance. This concept of Tsiolkovskiy has been under recent discussion again by some foreign researchers, for in case of the possible success of modeling of conditions of weightlessness by means of immersion in fluid, a prespective will be opened for the study of animal and human reactions upon their prolonged stay in the state of weightlessness. Of definite interest in this connection is the study of L. Knight who, in order to eliminate information coming from the otolithic apparatus, immersed experimental individuals

in water with their heads in such a position that the functional activity of the receptors (the otolithic apparatus) was considerably reduced. In this connection, the experimental subjects who had previously experienced the effect of weightlessness under conditions of flight indicated that they had experienced sensations similar to the ones they now felt during the state of weightlessness.

Further works in this direction will make it possible to establish definitely the expediency of the use of this method for the study of the effect of a prolonged stay of a human being in the state of weightlessness.

Tsiolkovskiy thought that animals and human beings finding themsleves in a state of weightlessness are, after a certain time, adjusted to this state, though he considered it probable that man in a weightless space may at first experience some illusory sensations -- disturbances of orientation in space. He wrote in regard to this: "Nevertheless these illusions, at least in living quarters, must disappear after a while. When we are on a ship, the shores seem to us to be in motion, but afterwards we are conscious that it is the ship that is moving. The same situation will probably occur in space...."(1)

Comparatively recently flights were conducted in planes according to a specially developed regimen whereby the fliers remained for 30 to 40 seconds in a state of weightlessness; in this connection, during the first flights some experimental subjects noted the appearance of illusory sensations as well as a considerable disturbance of the coordination of movements, especially in cases when the movements were effected without the control of vision. The results of these experiments showed that upon repeated stays under conditions of weightlessness, man adjusts himself and is able to effect correctly complicated motor actions. This can be judged from the photograph (Fig 3), in which is shown one of the experimental subjects during the state of weightlessness.

In studying the photograph our attention is attracted to the fact that the ceiling, floor, and the walls of the cabin are covered with mats which obviously are there to protect the experimental subject from jolts if he makes some awkward movement under conditions of complete loss of weight, or if he falls when conditions of weightlesness are removed

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(1) K. E. Tsiolkovskiy. "Purposes of Planetary Travel." Publishing House of Aerofleet, 1939, page 73.

from the plane and his body again acquires weight.

Fig. 3 An experimental subject in a state of weightlessness in a cabin

It is worth noting that Tsiolkovskiy, who had written picturesquely and at length on the effect of weightlessness on the life of man under conditions of space travel, thought that a prolonged stay of human beings under conditions of complete weightlessness must complicate their daily life to a considerable extent, and cause the astronauts much discomfort. In this connection Tsiolkovskiy suggested in 1895, for the first time, the creation of an artificial force of gravity by means of rotating the cabin of a space ship. According to Tsiolkovskiy's belief, the centrifugal force acting on the astronaut must be many times lower than the force of terrestrial gravity.

He wrote: "A gravity of one hundredth or even one thousandth of that of the earth's is entirely sufficient." (1) It is interesting to note that the idea of creating artificial gravity to ensure favorable living conditions for men during space flights was developed after Tsiolkovskiy in the works of the French scientist Robert Eno-Pel'tri. In 1912 he suggested the possibility of compensating for the absence of a field of gravity during a space flight by

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(1) K. E. Tsiolkovskiy. "Purposes of Planetary Travel," Publishing House of Aerofleet, 1939, page 76.

a field of accelerations, a suggestion which proves to be of little practical value since it requires a considerable additional expenditure of fuel in flight.

The creation of "artificial gravity" by means of rotation of the space ship was also suggested, after Tsiolkovskiy, by the American scientist Noel Deysh. (1) According to his project, the space rocket, after leaving the limits of the earth's atmosphere (when the aerodynamic properties connected with its shape will be of no importance), must be divided into two parts connected by a cable. By means of small supplementary rockets a rotatory motion will be created, but, since the cable may be 200 meters or more long, the field of acceleration of each half of the space rocket will change very slightly from one point to another, which will protect the astronaut from unpleasant sensations connected with rotation. This idea even now atracts the attention of foreign scientists who are working in the field of aviation and space medicine (Armstrong, Gaspa, etc.); it is widely discussed in foreign literature, but the name of Tsiolkovskiy remains undeservedly forgotten in these discussions.

In dreaming of the conquest of cosmic space Tsiolkovskiy wrote: "We can achieve the conquest of cosmic space by very simple tactics. Let us first solve the easiest problem: to establish a space station near the earth as its satellite." (2)

Having suggested the theoretical idea in regard to the creation of an artificial earth satellite inhabited by people, Tsiolkovskiy visualized very clearly that the realization of such a project is connected, in addition to engineering difficulties, with the necessity of solving a number of biological problems, since the creation of conditions needed for the maintenance of normal human activity during man's extended sojourn beyond the limits of the terrestrial atmosphere must encounter very great difficulties. In this connection, Tsiolkovskiy in his theoretical plan analyzed such important problems of ensuring human existence under the conditions of life on an artificial satellite as the maintenance of the normal gas composition of the satellite's "atmosphere," the possibilities of purposeful movement and

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(1) See R. Eno-Pel'tri. "Cosmic Flights," Oborongiz, 1950, page 126
(2) K. E. Tsiolkovskiy. "Collected Works," Vol 2, 1954, page 280

prolonged existence in space without gravity, the construction of living quarters of the most adequate shape, their illumination, etc.

Toward the end of the last century the famous Russian chemist, D. I. Mendeleyev, suggested the employment of hermetic space flight cabins in which barometric pressure approximating the terresrial could be maintained, and which, by utilizing compressed gaseous or liquid oxygen, would ensure the astronauts the required conditions for respiration. K. E. Tsiolkovskiy thought in this connection that the quarters which people will occupy inthe artificial satellite will also represent a hermetically closed space with a sufficiently high barometric pressure.

In their relatively brief flights into space -- for example, to the moon -- the astronauts will be able to utilize the oxygen reserves brought from the earth, while carbon dioxide harmful to the organism will be eliminated from the cabin air by means of the utilization of chemical substances (alkalies) which would absorb it. Thus, Tsiokovskiy postulated the idea of utilization of regenerating devices in hermetic cabins to ensure the needed conditions for life activity during brief space flights. This idea was developed brilliantly by Soviet scientists in carrying out medico-biological studies dealing with rocket launchings -- as well as with the second artificial earth satellite. It is known that the experimental animal -- the dog Layka -- was placed in a hermetically closed cabin of the regenerating type, in which the regeneration of oxygen and absorption of carbon dioxide were effected by means of highly active chemical compounds.

Tsiolkovskiy evidently assumed that under conditions of initial space flights the astronauts would be able to take along only a limited amount of food and water, and would therefore experience hunger and thirst. This supposition led young Tsiolkovskiy to decide to test the effect of hunger and thirst on himself. He described this experiment as follows: "I subjected myself to tests of not eating and not drinking for several days. At the end of this period I lost consciousness for several minutes." (1)

Life in hermetic cabins during a prolonged sojourn regarding space flights on long-lasting artificial earth satellites, or during flights to distant planets, obviously cannot be ensured by stores of oxygen and chemical substances for the absorption of carbon dioxide brought from the earth,

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(1) K. E. Tsiolkovskiy. "A Sketch of My Life," page 28.

since it would require excessively large reserves of chemicals. In this connection, an excessively large amount of food products and water also will be needed on the rocket premises. In this connection, Tsiolkovskiy suggested the creation of an artificial atmosphere on space ships, which would require the utilization of a definite area for a plant hothouse. He wrote: "Just as the earth's atmosphere is purified by plants with the aid of the sun, so can our artificial atmosphere be regenerated." (1) It will need -- as does the terrestrial atmosphere -- the maintenance of rotation of substances essential for human life -- oxygen and water and the ridding of carbon dioxide from the air. Tsiolkovskiy suggested that this idea be implemented by means of conducting special experiments in which "one could determine the smallest surface illuminated by the sun's rays that would be sufficient for a human being in regard to respiration and nutrition; one can seek and test plants which would fit this purpose." (2) At the present time this idea of Tsiolkovskiy is being widely discussed by biologists. Concrete experiments have begun on the selection of plants which eliminate oxygen in large quantities and absorb carbon dioxide, as well as plants suited for use as food by human beings. The attention of the majority of scientists has been attracted to the alga -- chlorella -- which they are attempting to utilize for this purpose.

The maintenance of normal thermal regimen in the cabin of a space rocket also presents a fairly complicated problem. Without its solution, however, it will be impossible to realize the flights of animals and human beings into space, since human beings and the higher animals can adjust themselves only to relatively slight variations of temperature, a fact which renders a considerable lowering or rise of temperature in a hermetic cabin intolerable. In order to regulate the temperature in the rocket Tsiolkovskiy suggested that one paint its surface in two colors -- white, which reflects sunlight well, and black, which absorbs heat well. In space flight the temperature in the cabin will vary and will depend on which side the rocket is turned toward the sun. In regulating the area of the reflecting surface and the size of the surface which absorbs heat by turning the rocket around so its bright surface faces the sun, or by turning it to the surface that has been painted black, one can regulate the temp-

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(1) Ibid, page 128.
(2) K. E. Tsiolkovskiy. "Collected Works," Vol 2, page 130

erature within the rocket and maintain it with sufficient accuracy at the needed level (+20°C). The same principle of maintaining the normal thermal regimen could, according to Tsiolkovskiy, be employed in maintaining a "comfortable temperature" within a space suit, whenever the astronauts will leave the space ship. This idea was expounded, subsequent to Tsiolkovskiy, by Robert Eno-Pel'tri, who, however, did not refer to the works of the great Russian scientist.

It is necessary to note that the principle of thermal regulation suggested by Tsiolkovskiy was utilized by the Belgian Scientist Picard and by Soviet builders in ensuring flights at high altitudes (16,000 to 22,000 m) in stratospheric balloons. Thus, the hermetic gondola of Picard's stratospheric balloon, which rose to an altitude of 16,000 m, was painted in two colors: black and white. A special construction permitted one to vary the position of the gondola, which made it possible to turn either the bright or the dark surface of the gondola to the sun, thus regulating the temperature within.

Tsiolkovskiy thought that under certain conditions man could leave his habitation and, by using special protective means against the fatal effect of highly rarefied cosmic space, undertake travel along the surface of the moon and other planets of the solar system. In addition, he understood that the astronauts will also need special clothing in the case of damage during the flight, when the habitation occupied by the travellers might lose its hermeticity. In order to prevent the dangerous effect of cosmic space, Tsiolkovskiy suggested the use of a scaphander /space suit/ -- a special suit in which, when the barometric pressure in the external envirnment is reduced, the needed pressure is automatically created around the astronaut's body, and oxygen in quantity sufficient for respiration is supplied under the helmet of the space suit.

The development of high altitude aviation also led to the necessity of developing such suits for aviators. The present-day high altitude suits and scaphanders enable man to operate under conditions of extremely low barometric pressure. In this connection, pressure created by the suits on the surface of the human body prevents the development of the phenomenon of boiling of the fluid tissues of the organism, which takes place under conditions of extremely low barometric pressure, while oxygen entering under the helment ensures normal respiratory functions.

The possibility of the successful use of scaphanders in rescues from the unfavorable effect of highly rarefied upper atmospheric layers was demonstrated by a group of Soviet scientists in experiments on animals.

In these experiments, after the animals had reached altitudes of over 100 km, in rockets a catapulting was performed at the altitude of 75 to 90 km during the free fall of the rocket -- an automatic expulsion of the animals from the rocket -- following which the animals protected by high altitude space suits descended in parachutes for a relatively extended period of time -- about one hour. This experiment was successfully tolerated by the experimental dogs, some of them having already made two successful flights into the upper atmospheric layers. Thus, by means of these experiments, the correctness of one of Tsiolkovskiy's concepts has been substantially corroborated.

We live at a time when the ideas of Tsiolkovskiy are being translated into reality: his scientific heritage is fruitfully utilized not only by scientists, builders, and engineers who construct space ships, but also by physicians and biologists who work in a new field of science -- space medicine.

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